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## **Characterization of Hardware Improvements to an Acoustics-based Tripwire Detection Method**

**by W.C. Kirkpatrick Alberts, II, David A. Ligon, and Mark A. Coleman**

**ARL-TR-5799**

**October 2011**

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Computational and Information Sciences Directorate, ARL

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A method of detecting tripwires by monitoring the noise produced by airflow across a wire [Sanchez and Alberts, ARL-TN-0379] showed that various wires could be detected out to ranges of 5 cm. This short range is unacceptable if the technique is to be considered useful. Therefore, several improvements have been enacted with the goal of increasing the operating range of the technique. This report details the hardware improvements and their effect on the operating range of the detection method.				
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## **Contents**

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<b>List of Figures</b>	<b>iv</b>
<b>1. Introduction</b>	<b>1</b>
<b>2. Hardware Improvements and Experimental Configuration</b>	<b>1</b>
<b>3. Results and Discussion</b>	<b>3</b>
<b>4. Concluding Remarks</b>	<b>7</b>
<b>5. References</b>	<b>9</b>
<b>Appendix A. Noise Spectra from Different Wire Types</b>	<b>11</b>
<b>Distribution List</b>	<b>14</b>

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## List of Figures

---

Figure 1. Sketch of nozzle used during most recent experiments.....	1
Figure 2. Sketch of experimental configuration with the baffle installed between the nozzle and the microphone.....	2
Figure 3. Noise spectra of the nozzle used during the feasibility study (blue) and of the nozzle machined for the experiments reported here (red). .....	3
Figure 4. Wire noise spectra normalized by the nozzle noise with no wire present: (a) original nozzle and (b) new nozzle. In each plot the blue curve corresponds to a nozzle wire separation of 2 cm, green to 4 cm, red to 6 cm, light blue to 8 cm, purple to 10 cm, yellow to 12 cm, and black to 14 cm. ....	4
Figure 5. Results of changing the separation between the microphone and the nozzle: (a) 6 cm between nozzle and microphone, (b) 9 cm, (c) 12 cm, and (d) 15 cm. Color representations are the same as in figure 4. ....	5
Figure 6. Normalized noise spectra resulting from the insertion of a baffle between the nozzle and the microphone. Color representations are the same as in figure 4. ....	6
Figure 7. Noise recorded from the nozzle without (a) and with (b) the baffle installed between the microphone and the nozzle at various nozzle-microphone vertical separations: blue is a separation of 3 cm, green 6 cm, red 9 cm, black 12 cm, and purple 15 cm.....	6
Figure 8. Results of changing the separation between the microphone and the nozzle with the baffle installed: (a) 6 cm between nozzle and microphone, (b) 9 cm, (c) 12 cm, and (d) 15 cm. Color representations are the same as in figure 4. ....	7
Figure A-1. Results of changing the separation between the microphone and the nozzle with white cotton string as the target:( a) 3 cm between nozzle and microphone, (b) 6 cm, (c) 9 cm, (d) 12 cm, and (e) 15 cm. Color representations are the same as in figure 4. ....	12
Figure A-2. Results of changing the separation between the microphone and the nozzle with thin steel wire as the target: (a) 3 cm between nozzle and microphone, (b) 6 cm, (c) 9 cm, (d) 12 cm, and (e) 15 cm. Color representations are the same as in figure 4.....	13

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## 1. Introduction

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In a recent ARL Technical Note, Sanchez and Alberts showed that air flowing through a narrow nozzle could, when directed over a wire, generate broadband acoustic noise in excess of the nozzle noise (1). Thus, they demonstrated the feasibility of detecting wires using this technique. However, they also showed that, with their experimental configuration, the separation between the nozzle and the wire was limited to 5 cm to successfully detect the noise due to the flow of air over the wire (1, 2). In order to address this severe limitation of the technique, we investigated several hardware modifications. This report describes the modifications and their effect on the operating range of the technique.

The next section describes the hardware changes and the experimental configuration. Section 3 presents the experimental results and discussion of those results. The final section offers some concluding remarks.

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## 2. Hardware Improvements and Experimental Configuration

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The nozzle used during the feasibility study was a re-purposed pipe-to-tubing barb fitting with a nozzle opening of 2.3 mm. While this nozzle helped demonstrate the feasibility of the technique, it was not designed to create a laminar flow into free air. Thus, the air stream spread rapidly at high flow rates, which contributed to the short range. To address this issue, we designed and machined another nozzle, figure 1. The new nozzle was designed and machined with the primary goal of creating as laminar a flow as possible from the nozzle opening, i.e., extensive effort was placed into creating smooth transitions between diameters and into creating smooth inner surfaces.

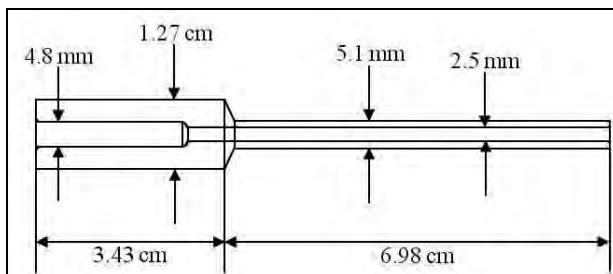


Figure 1. Sketch of nozzle used during most recent experiments.

Another issue encountered during the initial project was the overwhelming noise directly from the nozzle. Two methods to address the nozzle noise and, therefore, increase the operating range were to insert a baffle between the nozzle and the microphone and to increase the separation

between the microphone and the nozzle. The former simply adds a diffracting edge that limits the high-frequency noise reaching the microphone (3). The latter relies on geometrical spreading to reduce the nozzle noise at the microphone (4).

In order to examine the benefit to the tripwire detection technique of each of the above improvements, the apparatus used during the feasibility study was modified to enable increased separation between the nozzle and the microphone. We accomplished this by adding a longer rod to which the nozzle and microphone were attached. Further, a mount was added to the side of the nozzle holder to allow the attachment of a small baffle between the nozzle and the microphone. The small baffle was constructed of sheet aluminum with the following dimensions: a thickness of 1 mm, a width of 12.5 cm, and a length of 9.1 cm. The baffle was positioned 1.16 cm above the nozzle and protruded 3 mm in front of the nozzle. Figure 2 shows a sketch of the baffle installed between the nozzle and the microphone.

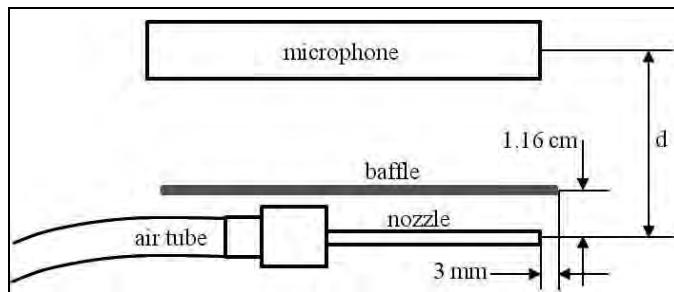


Figure 2. Sketch of experimental configuration with the baffle installed between the nozzle and the microphone.

During the feasibility study, we found that tension had little effect on the generated noise and that an approximate flow rate of 0.5 L/sec generated sufficient signal at the maximum range of 5 cm. Therefore, a flow rate of 0.5 L/sec was used during the work reported here and wire tension was not monitored. However, the wires used during this work were kept taut to keep the wire as horizontal as possible. The vertical separation between the microphone and the nozzle was varied from 3 to 15 cm in steps of 3 cm, see  $d$  in figure 2. At each separation step, the wire was removed from the apparatus and the nozzle noise was recorded. Then the wire was replaced and the wire noise was recorded at each range from 2 to 14 cm in steps of 2 cm. The baffle was then inserted into the apparatus and the first two sequences were repeated. The entire sequence of 80 measurements was repeated for each of three wires: insulated speaker wire (single conductor), white cotton string, and steel wire. The three wires had approximate diameters of 2.93 mm, 2 mm, and 0.64 mm, respectively.

The microphone used was a half inch Brüel and Kjær type 4192 pressure field microphone. The microphone signal was fed through a 25 Hz to 20 kHz bandpass filter before being digitized at a sampling rate of 40 kHz.

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### 3. Results and Discussion

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In the feasibility study, the single nozzle with a flow of 0.5 L/sec was found to be the most effective at generating the maximum sound from the widest variety of wires. Thus, the design for the new nozzle relied heavily on some of the dimensions on the original nozzle. The diameter of the new nozzle is similar to the old. Figure 3 compares the noise generated by the original single nozzle and the newly machined nozzle. Note that the newly machined nozzle creates from 5 to 15 dB, relative to 20  $\mu$ Pa, more noise than the original nozzle.

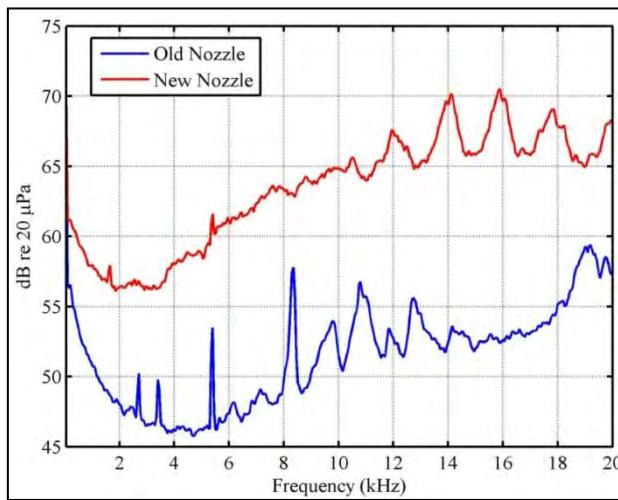


Figure 3. Noise spectra of the nozzle used during the feasibility study (blue) and of the nozzle machined for the experiments reported here (red).

Figure 4a is a plot of the noise generated by air from the original nozzle flowing over a single strand of speaker wire. The air had a flow rate of 0.5 L/sec and the nozzle wire separation varies from 2 cm to 14 cm in steps of 2 cm. Similarly, figure 4b shows the noise generated by air from the new nozzle flowing over the same wire under the same conditions. When the two plots are compared, it is apparent that the new nozzle and its associated upstream hardware generate sufficient noise from the wire to enable detection out to 6 cm, while the old nozzle generates sufficient noise for detection out to 8 cm. Although the new nozzle generates more self noise than the old nozzle, it will be used exclusively in the following discussions relating to the baffle and to separating the nozzle and microphone.

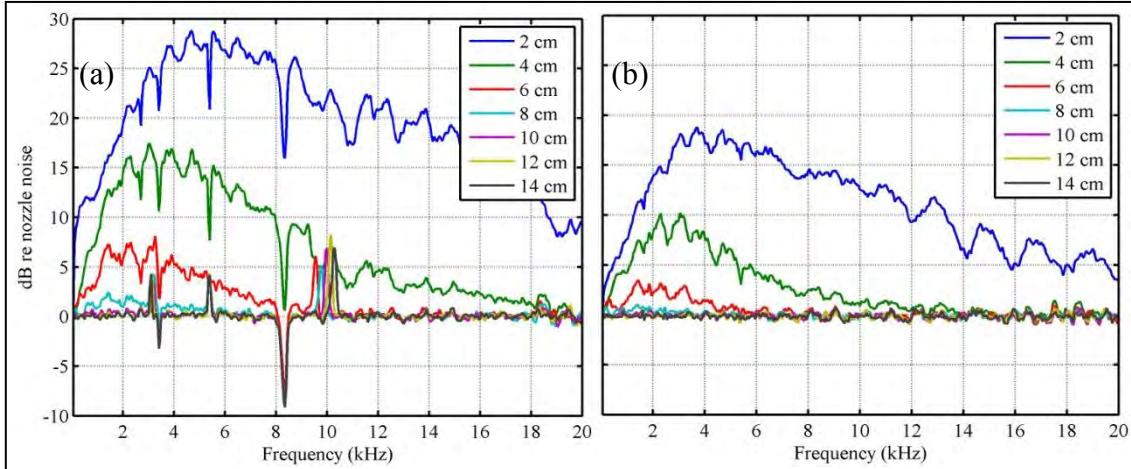


Figure 4. Wire noise spectra normalized by the nozzle noise with no wire present: (a) original nozzle and (b) new nozzle. In each plot the blue curve corresponds to a nozzle-wire separation of 2 cm, green to 4 cm, red to 6 cm, light blue to 8 cm, purple to 10 cm, yellow to 12 cm, and black to 14 cm.

Because the nozzle-wire separation appears to be limited by the level of noise created by the nozzle, alternative mechanical means of increasing the nozzle-wire separation needed to be explored. Two obvious means of decreasing the nozzle noise at the microphone are to increase the separation between the nozzle and the microphone and to insert a barrier between the nozzle and the microphone. Figure 5 shows the results of increasing the separation between the nozzle and the single speaker wire. If figure 4b and figures 5a through 5d are compared, it is apparent that as the separation between the nozzle and the microphone was increased, the noise level due to the wire increased relative to the nozzle noise. Thus, as the separation increased, the wire becomes detectable at greater ranges. As shown in figure 5d, the wire can be detected out to 14 cm in the 50 to 2000 Hz frequency range. This represents a nearly threefold increase in the range of the technique. Similar plots for the noise generated by flow over white cotton string and thin steel wire are shown in appendix A. While the plots in appendix A show that increasing the nozzle-microphone separation does increase the detection range, the range decreases as the wire diameter decreases. This phenomenon was observed in the initial work (1, 2). This implies that for optimal detection that the nozzle diameter should be similar in size or smaller than the diameter of the wire.

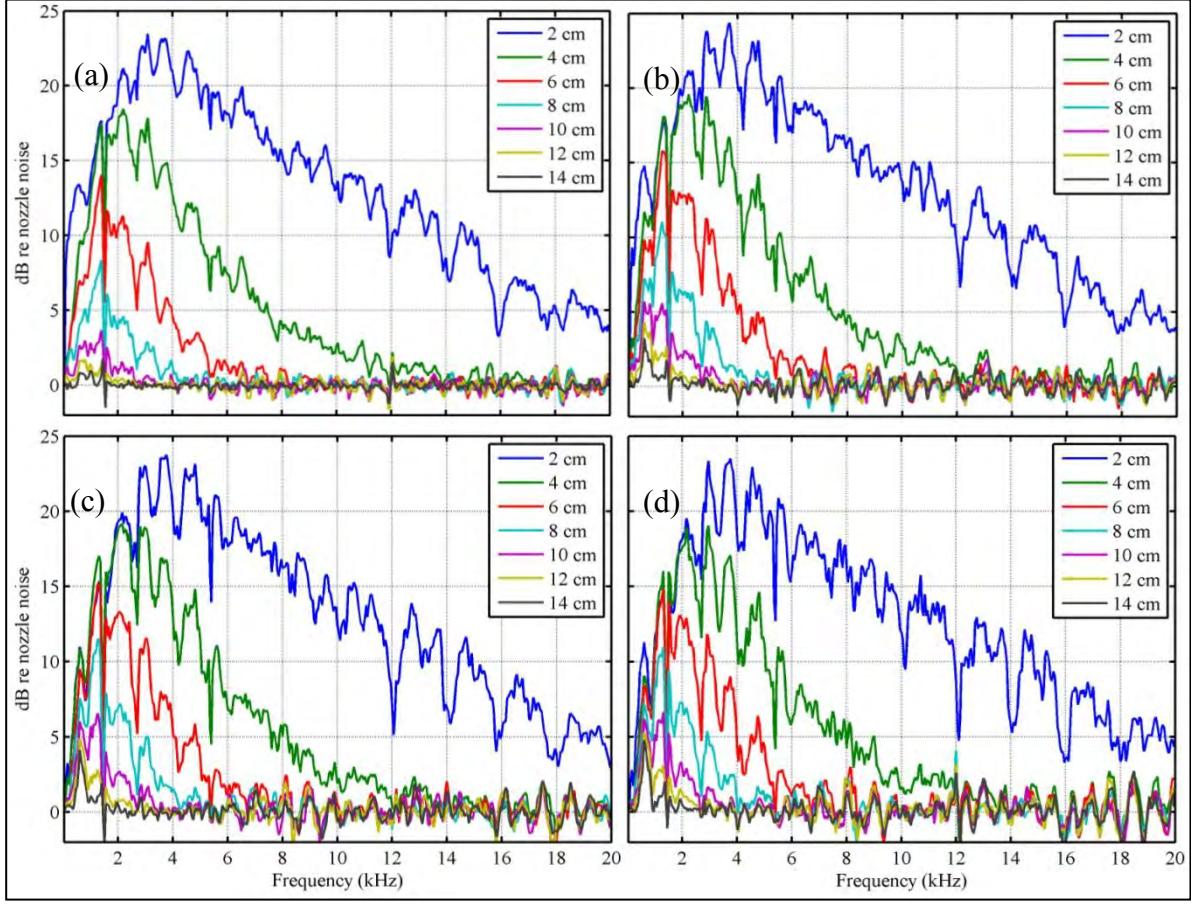


Figure 5. Results of changing the separation between the microphone and the nozzle: (a) 6 cm between nozzle and microphone, (b) 9 cm, (c) 12 cm, and (d) 15 cm. Color representations are the same as in figure 4.

The second mechanical augmentation with the aim of decreasing the nozzle noise at the microphone was to insert a baffle between the nozzle and the microphone. Figure 6 shows the results of inserting the baffle between the nozzle and the microphone at a microphone-nozzle vertical separation of 3 cm. Comparing the spectra in figure 6 to those in figure 4b it is apparent that there is a 3–5 dB increase in the noise levels, above roughly 7 kHz, in the spectra recorded with the baffle in place. This is not unexpected since the baffle, a diffracting element, acts as a low-pass filter for the noise generated directly by the nozzle (3). Because the baffle's effects are limited to the higher frequencies, the insertion of the baffle yields no increase in detection range at this microphone-nozzle separation. This could be potentially addressed by extending the baffle farther beyond the nozzle to change the angle through which the nozzle noise must diffract to reach the microphone, but, in practice, having the baffle ahead of the nozzle would greatly increase the risk of contacting a wire with the baffle rather than the airflow.

Figure 7 further illustrates the effect of inserting the baffle. Figure 7a shows noise spectra of the nozzle with no wire present at several vertical nozzle-microphone separations,  $d$  in figure 2. As might be expected, the rough shape of the nozzle noise spectrum remains unchanged, but the

overall level decreases per geometrical spreading. Figure 7b shows the spectra after inserting the baffle in each of the same nozzle-wire vertical separations. The baffle tends to flatten the overall noise spectrum by lowering the level at frequencies above 6 kHz while raising the noise level between roughly 500 Hz and 6 kHz.

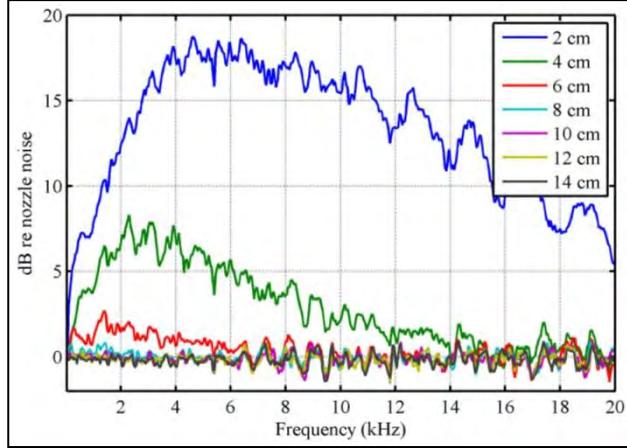


Figure 6. Normalized noise spectra resulting from the insertion of a baffle between the nozzle and the microphone. Color representations are the same as in figure 4.

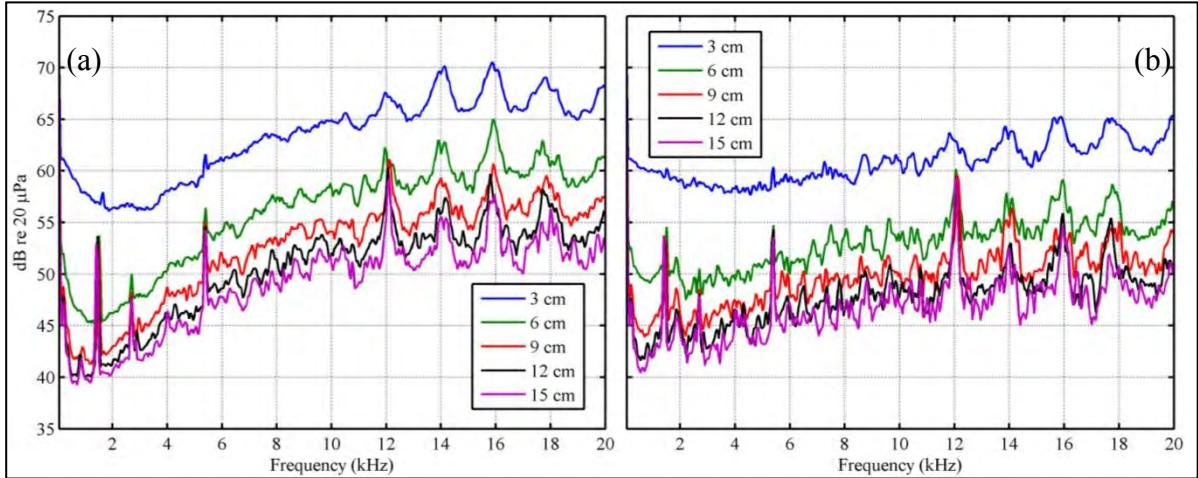


Figure 7. Noise recorded from the nozzle without (a) and with (b) the baffle installed between the microphone and the nozzle at various nozzle-microphone vertical separations: blue is a separation of 3 cm, green 6 cm, red 9 cm, black 12 cm, and purple 15 cm.

Based on the observations in figure 5, where the lowest frequencies are where the wire is detected at the longest ranges, the insertion of the baffle may have little or no effect on the ability to detect the wire at longer ranges. This is borne out by figure 8, four plots showing the effect of increasing the nozzle-microphone separation with the baffle installed. Comparing figure 8 and figure 5, there appear to be only subtle changes between the baffle and no baffle scenarios. Thus, it can be concluded that the baffle in the configuration used for this work is not a useful

addition to the apparatus since the baffle has little or no effect on the ability to detect tripwires using airflow.

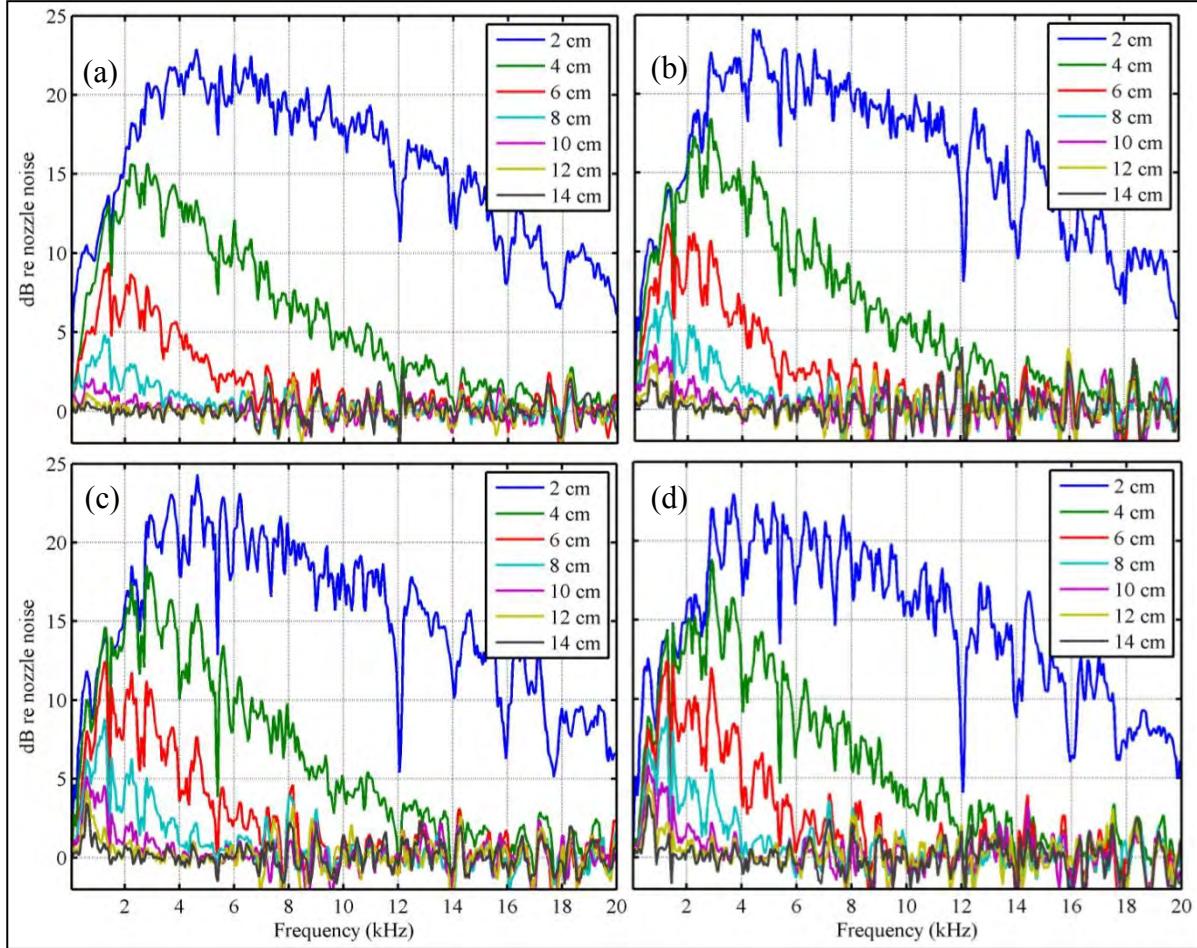


Figure 8. Results of changing the separation between the microphone and the nozzle with the baffle installed:  
 (a) 6 cm between nozzle and microphone, (b) 9 cm, (c) 12 cm, and (d) 15 cm. Color representations are the same as in figure 4.

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#### 4. Concluding Remarks

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In this report three augmentations to an existing acoustics-based tripwire detection method have been described: a carefully designed nozzle, increased vertical separation between the microphone and the nozzle, and a baffle inserted between the microphone and the nozzle. Each of the augmentations was investigated experimentally and it was found that increasing the vertical separation between the microphone and the nozzle had the only appreciable positive effect on the detection range. Increasing the vertical separation resulted in an almost three-fold increase in detection range. Inserting the baffle between the microphone and the nozzle

predominantly decreased the nozzle noise as measured at the microphone, which is consistent with the expected low-pass filter effect of a diffracting element. The nozzle used throughout this work, despite careful design to laminarize the flow through the nozzle, generated higher noise levels than the nozzle used in the initial investigation of this technique. Despite considerable increases in detection range due to the hardware modifications presented here, the improvements are not sufficient to warrant further investigation of the technique.

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## 5. References

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1. Sanchez, K.; Alberts, II, W.C.K. *Examining the Feasibility of a Method of Tripwire Detection Using Acoustics*; ARL-TN-0379; U.S. Army Research Laboratory: Adelphi, MD, 2009.
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3. Pierce, A. Diffraction of Sound Around Corners and Over Wide Barriers. *J. Acoust. Soc. Am.* **1974**, *55*, 941.
4. Kinsler, L. E.; Frey, A. R.; Coppens, A. B.; Sanders, J. V. *Fundamentals of Acoustics*; Third Edition, John Wiley & Sons, New York, 1982.

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## **Appendix A. Noise Spectra from Different Wire Types**

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Contained in this appendix are spectra from two different wire types; an un-insulated steel wire and a white cotton thread. These results have been briefly mentioned in section 3 following the discussion of figures 4 and 5.

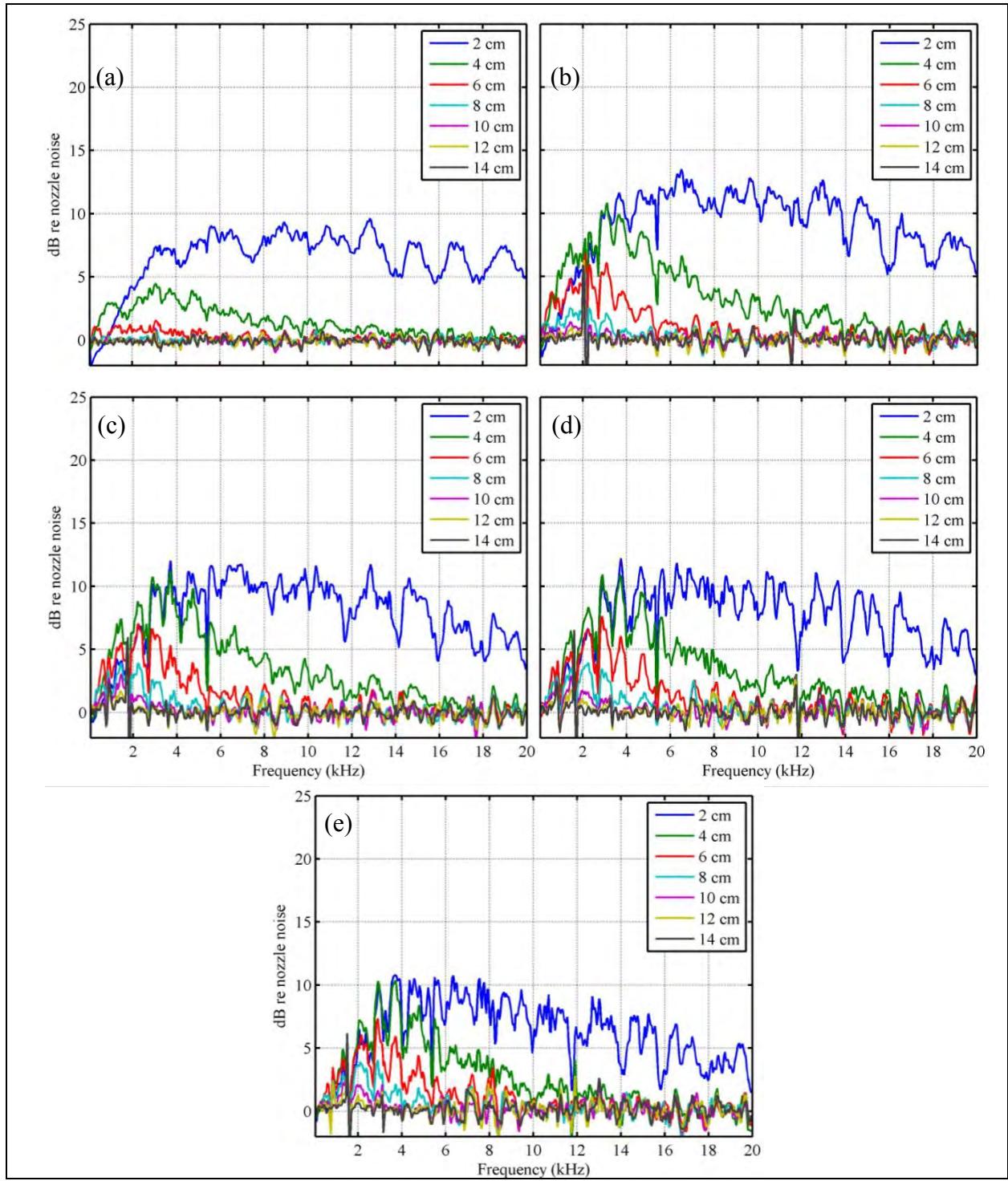


Figure A-1. Results of changing the separation between the microphone and the nozzle with white cotton string as the target: (a) 3 cm between nozzle and microphone, (b) 6 cm, (c) 9 cm, (d) 12 cm, and (e) 15 cm. Color representations are the same as in figure 4.

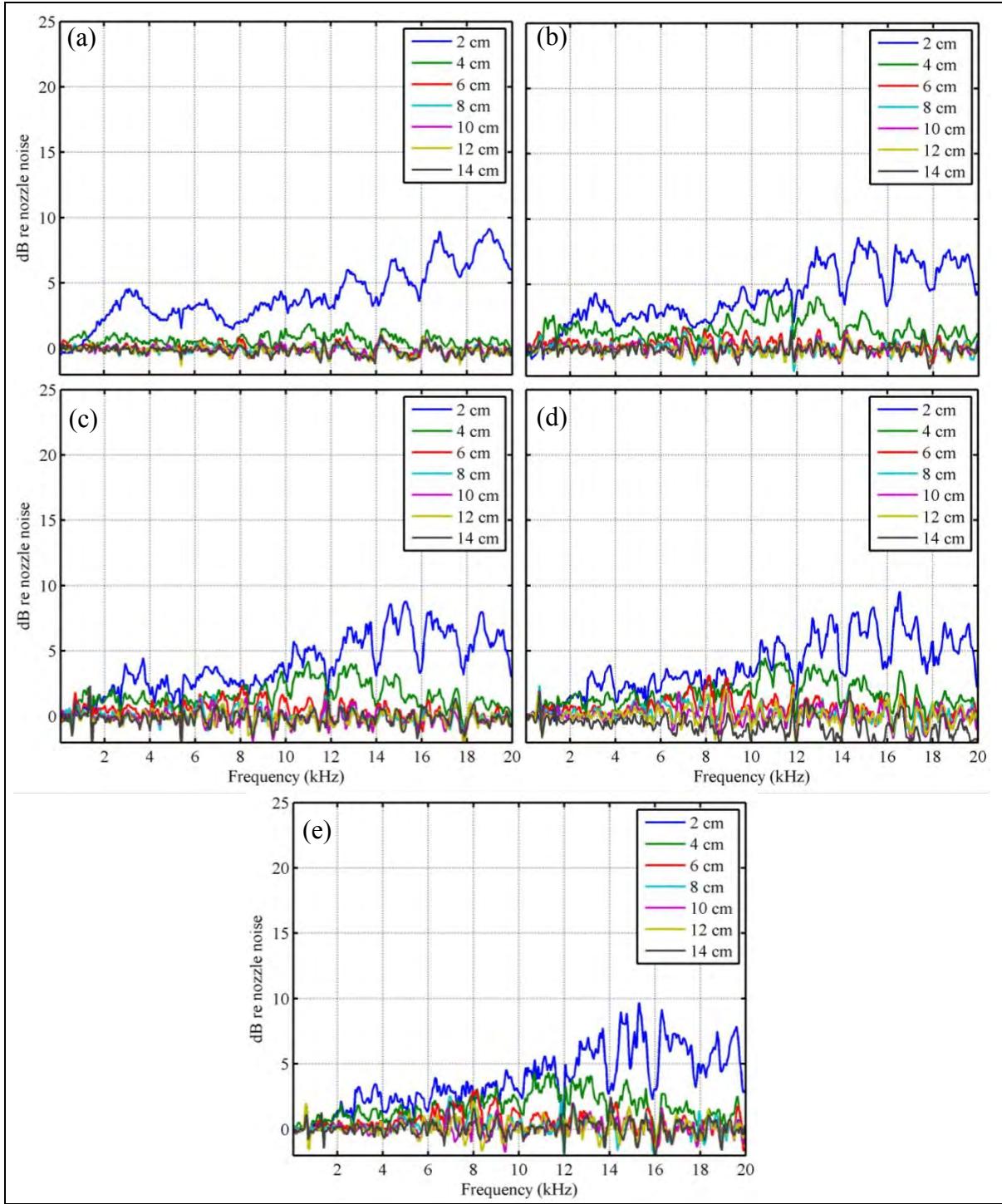


Figure A-2. Results of changing the separation between the microphone and the nozzle with thin steel wire as the target: (a) 3 cm between nozzle and microphone, (b) 6 cm, (c) 9 cm, (d) 12 cm, and (e) 15 cm. Color representations are the same as in figure 4.

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